

# FUZZY LOGIC CONTROL OF INTELLIGENT VEHICLE SYSTEMS

Cezary Szczepaniak

Andrzej Szosland

Vehicle Research Institute, Technical University of Lodz, POLAND

ID # 470

## ABSTRACT

The purpose of presented analysis is to examine the possibility of improving vehicle performances by exploiting automatic devices fitted to a vehicle. The paper presents the results of investigations of vehicle dynamics, which is equipped with an antilocking braking device (ABS) and traction control one (TCS). A four-wheel non-linear model of a car is applied. The algorithms of control of ABS as well as TCS are proposed. Their technical realisation is done by means of fuzzy logic method. The paper outlines the process used to create fuzzy sets and the rules that define the fuzzy controllers. The obtained results of the simulation presents the effectiveness of ABS and TCS in different road situations.

**KEYWORDS** *antilocking ABS, traction control TCS, fuzzy control, motor vehicle*

## NOTATION

$a$  - distance from c.g. to front axle  
 $b$  - distance from c.g. to rear axle  
 $C$  - stiffness  
 $F_{z,x,y}$  - vertical (z), longitudinal (x)  
lateral (y) forces acting on a wheel  
 $h$  - height of c.g.  
 $K$  - dampness  
 $L$  - wheel base  
 $M$  - mass of vehicle  
 $R$  - radius of wheel  
 $V$  - vehicle velocity  
 $\beta$  - sideslip angle  
 $\Phi$  - pitch angle  
 $\Psi$  - yaw angle  
 $\Theta$  - roll angle  
 $\Omega$  - wheel rotational speed  
 $\mu$  - adhesion coefficient

## INTRODUCTION

The functions of intelligent vehicle cannot be assured without highly sophisticated electronic appliances supporting a driver and environment, which should be also prepared for the utilisation of these electronic

devices. That's why it is necessary to evaluate the stability of motion of vehicle equipped with different automatic devices in various road conditions. It is also important to investigate a mutual influence of particular devices to the operation of the others. All of that allows to ensure enhanced safety and comfort travelling during vehicle motion.

This paper refers to the influence of automatic control systems action upon vehicle motion. The application of antilocking device ABS and traction control TCS, which were integrated into one device, were considered. The same sensors, actuators and electronic control unit were used to fullfill the functions of both devices. This is a part of investigations carried out at the Technical University of Lodz, focused on the development of automatic control devices and their integration into control system of vehicle dynamics [5], [6], [7], [8].

The control algorithms of presented devices are realised by means of a fuzzy logic. This method formulates the relationship between the input and the output of the controller which allow to applicate the human knowledge to the processes. The main advantage of using fuzzy logic is to reduce the very detailed models of particular subsystems and necessity to describe the phenomena by commonly used very complicated mathematical formulas.

## VEHICLE MODEL

The vehicle model consists of lumped masses: a sprung mass representing the body of the vehicle and four unsprung masses representing the wheels. The sprung mass is treated as a rigid one and is connected with the wheels by means of springs and damping elements. The simplified physical model of a vehicle is shown in Fig.1.

The vehicle motions are defined with reference to a right-hand co-ordinate system  $Ox_pY_pZ_p$  with originates at its c.g. and which travels with the vehicle. It allows to describe car vertical motion, as well as roll about  $X_p$  axis, pitch about  $Y_p$  axis and yaw about  $Z_p$  axis. The vehicle attitude and trajectory are defined with respect to a right-hand orthogonal axis system  $OXYZ$  fixed on the ground. Second-

ordered Lagrange equations have been used to describe the dynamics of motion of the vehicle model.

The relationships describing the non-linear characteristics of the tyres are based on Dugoff hypothesis, adapted to the parameters of the considered vehicle.

The discussed model describes heavy vehicle domain characteristics. Its total mass is equal to 10000 kg, wheel base  $L = 6$  m, the distance from c.g. to front axle  $a = 2.2$  m, height of c.g.  $h = 1.5$  m, wheel radius  $R = 0.5$  m.

### ANTILOCKING ABS AND TRACTION CONTROL TCS MODELS

The analysed ABS is a three-stage device developed in the Vehicle Research Institute. It is designated for pneumatic braking systems and is used in buses, trucks and trailers. The operation mode assures its work as an individual control of each wheel or common, select low at the rear axle. The mode of operation can be arranged according to the customer demand. The whole construction is an add-on (overlap) solution, which does not change the principal braking system and allows to brake a vehicle conventionally in the case when the ABS is switched off. The base of functioning of a device is to follow the angular speed of each wheel and to compare it with 'programmed velocity' which corresponds to vehicle velocity. On a base of these two functions the wheel slip  $s_x$  can be calculated. Assuring the difference between these two velocities allows to utilise the maximum adhesion forces and protect wheels against locking. All differences greater than assumed value effect the generation of signals which control the modulator valves in braking system. Such operation causes the decrease of braking torque. When the electronic control unit states the tendency of a wheel to be locked, the braking pressure is decreased and it protects the wheel against locking. The difference between wheel and vehicle velocity smaller than assumed causes appearing such control signals which allow to increase the pressure in braking system and increase the effectiveness of braking. Since to the costs of a sensor which can measure vehicle velocity are still rather high, the real value of car speed is substituted by 'programmed velocity'. The shape and values of "programmed velocities" are the original proposals for this solution.

The discussed solution of TCS allows to follow the power transmitted to the wheels and to reduce it in a case of appearing the surplus of longitudinal forces

in comparison to the adhesion. For this purpose it is realised by means of applying the braking torque in any of driven wheels and limiting the power transmitted from an engine. The electronic control unit compares the angular speed of each driven wheel with the velocity of vehicle. The vehicle velocity is calculated on the base of the angular speed of undriven wheels. Comparing these two velocities the slip of driven wheels can be counted. When the slip during acceleration increases, the braking modulator is activated and the injection fuel pump is cut off.

Both devices are integrated into one unit. The same wheel speed sensors are used, as well as the same braking modulator valves. These valves are specially designed to fulfil the functions of ABS and TCS operations.

The control unit follows the input signals from the sensors and generates the output signals which can force the operation of braking modulators and fuel pump. The technical realisation of the control unit is prepared by means of fuzzy logic. It operates using the same fuzzy sets describing input and output physical signals. The main feature of applied till now conventional method of control is describing the algorithm of control by means of algebraic, differential or others equations. To improve the operation of the devices it is necessary to utilise the human knowledge about the process. Transforming this knowledge into mathematical model is rather difficult in a case of conventional control. It is relatively easier by using the fuzzy logic theory. Defining the forms of input and output fuzzy sets, preparing the control algorithm in a form of logic rules, it is possible to prepare the characteristics of ABS or TCS regulators.

Any particular variable can be represented by unique fuzzy set. In the presented principle programmed velocity corresponding the vehicle velocity is represented by the fuzzy set (LVV), angular velocity of driven wheels by the fuzzy set (LWV) and additionally wheels slip by the fuzzy set (LWS). These variables are chosen as input signals. The output signals are the value of control signal of particular wheel brake modulator (represented by the fuzzy set LSB) and the value of control signal of engine torque (fuzzy set LET).

For particular sets it can written:

$LVV = \{ZE, PS, PE, PM, PB, PU, PV\}$

$LWV = \{NB, NM, NE, NS, ZE, PS, PE, PM, PB\}$

$LWS = \{ZE, PS, PE, PM, PB, PU, PV\}$

$LSB = \{PO, ZE, NE\}$

$LET = \{PO, ZE, NE\}$

It is assumed the following fuzzy subsets describing above variables as follows: positive big (PB), positive medium (PM), positive small (PS), zero (ZE), negative small (NS), negative medium (NM), negative big (NB), etc.

Various shapes of fuzzy subsets can be used. In this paper the triangle  $\Delta$ ,  $\square$  gamma  $\Gamma$  and L have been involved. The reason of their application is the short time of computation of their values as well as their ability to store the information needed for the fuzzy controller.

The graphical presentation of fuzzy set *L<sub>VV</sub>* in the range [0.0,+25], fuzzy set *L<sub>WV</sub>* in the range [-100,+100], fuzzy set *L<sub>WS</sub>* in a range of [-1,+1] and fuzzy set *L<sub>SB</sub>* in a range [-1,+1] are shown in Fig. 2.

The next step is to define the relationships between inputs and outputs. It can be created by the use of descriptive phrases rules. These rules determine the control of fuzzy controller. 35 logic rules have been prepared for the fuzzy controller ABS and 98 ones for the fuzzy controller TCS.

Some examples of them for ABS:

rule no.6

if (WV) is (ZE) and (WS) is (NB) then (SB) is (NE);

rule no.13

if (WV) is (PE) and (WS) is (NS) then (SB) is (PO);

rule no.23

if (WV) is (PB) and (WS) is (PS) then (SB) is (ZE);

and for TCS:

rule no.16

if (WV) is (ZE) and (WS) is (NB) then (SB) is (NE);

if (WV) is (ZE) and (WS) is (NB) then (ET) is (NE);

rule no.24

if (WV) is (PE) and (WS) is (PS) then (SB) is (NE);

if (WV) is (PE) and (WS) is (PS) then (ET) is (PO);

The antecedent consists of logical operation “AND” – relation between input values, and the consequent describes the resultant state of braking modulator valve for ABS and TCS as well as an engine torque for TCS.

The resultant minimum membership levels of these rules become the membership values of the output signal fuzzy subsets. They create the activation level of each rule. The implication of all values of output signal allow to form the operational algorithm of the electronic control unit of the device.

## SIMULATION RESULTS

The ABS functionality was checked during various numerical tests and verified by road tests performed

in the same conditions. The braking on a  $\mu$ -split surface characterised by different values of adhesion coefficient for the left  $\mu=0.6$  and the right wheels  $\mu=0.2$ , is presented in Fig.3. It shows the velocity of a vehicle *V*, the linear velocity of front left *V<sub>K1</sub>* and front right wheel *V<sub>K2</sub>*, and the braking pressure - *p<sub>H1</sub>* and *p<sub>H2</sub>*.

The functionality of TCS was analysed in a series of numerical investigations performed for the same road conditions as for braking. Some exemplary results for accelerating on a homogenous surface  $\mu=0.2$  are shown in Fig. 4.

The results of simulation tests of motion of a vehicle equipped with integrated ABS/TCS device were compared with these, obtained for a vehicle, without any automatic control systems. The series of numerical investigations were done for different types of surfaces, different velocities and different courses of driving while braking and accelerating. The longitudinal and lateral forces are shown in Fig.5 presented in a form of solid lines. The shadow area corresponds to the forces of vehicle without ABS and TCS devices. The maximum possible force for analysed road conditions, which is also indicated on this graph as an boundary value, is adequate for the surface adhesion coefficient  $\mu = 0.6$ .

## CONCLUSIONS

This paper presents the solutions of the antilocking and traction control devices, obtained by means of the fuzzy logic controller.

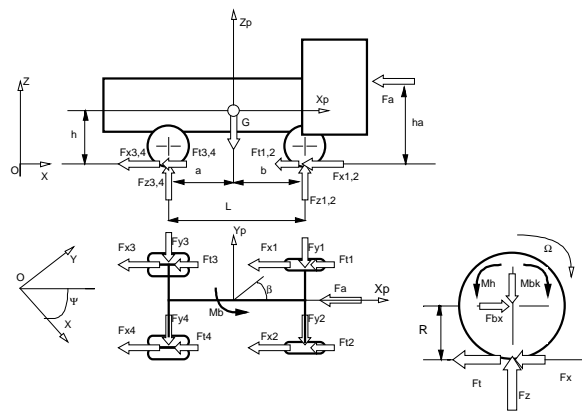
Analysing the results of simulation of the operation of the antilocking controller ABS it can be said, that it improves the characteristics of the force utilisation (good tire-road contact) and can enhance the vehicle stability and handling characteristics during sudden, panic braking. The similar effect occurs during acceleration while traction controller TCS works. It greatly improves the efficiency of vehicle performances.

No disturbances were noticed in the functionality of the ABS or TCS, extorted by different road conditions and driver action.

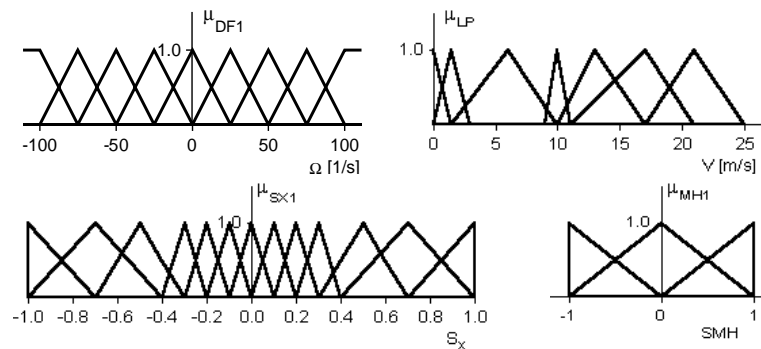
5. Szczepaniak C., Szosland A. "Simultaneous Operation of ABS and 4WS – Simulation Stud

## REFERENCES

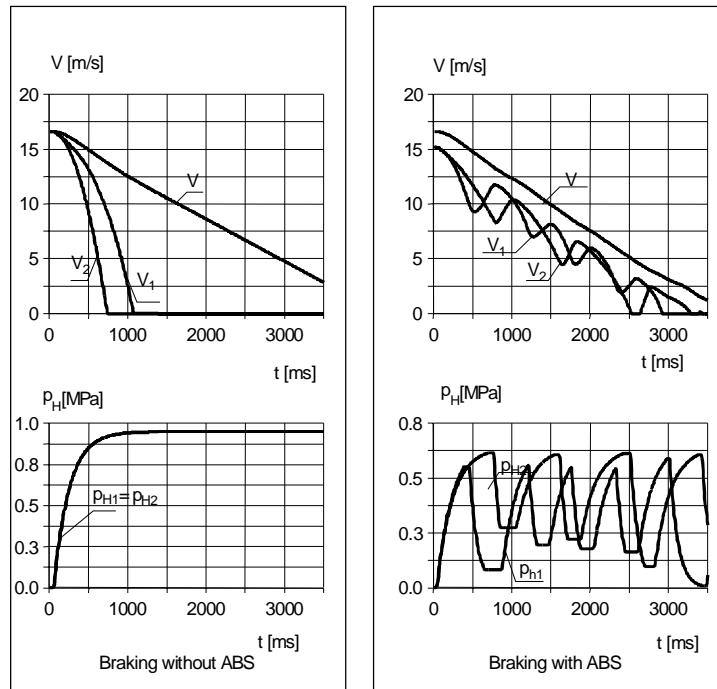
1. Davis L.I., Puskorius G.V., Yuan F., Feldkamp L.A. "Neural network modeling and control of an anti-lock brake system" Intelligent Vehicles Symposium 1992
2. Kozo Fujita, Ise K., Inoue Y., Akita K. "Development of Vehicle Integrated Control System" Toyota Technical Revue vol.43 no.1 1993
3. Layne J.R., Passino K.M., Yurkovich S. "Fuzzy Learning Control for Antiskid Braking Systems" IEEE Transactions on Control Systems Technology 1993
4. Mastinu G., et al. "Integrated Controls of Lateral Vehicle Dynamics" Vehicle System Dynamics 22 1993
5. Szczepaniak C., Szosland A. "Simultaneous Operation of ABS and 4WS – Simulation Stud
6. Szczepaniak C., Szosland A. "The Integrated Control Systems of Vehicle Dynamics" Proc. of Intern. Conference 'Science and Motor Vehicles' Beograd 1997
7. Szczepaniak C., Grabowski J., Szosland A. "Some Problems of Vehicle Dynamics – Simulation Studies" ImechE C229/86 1986
8. Szczepaniak C., Grabowski J., Szosland A. "Some Problems of Vehicle Brakes and Braking" Vehicle System Dynamics 1987
9. Takashi H., Ishikawa Y. "Anti-Skid Brake Control System Based on Fuzzy Interference" US Patent 4.842.342



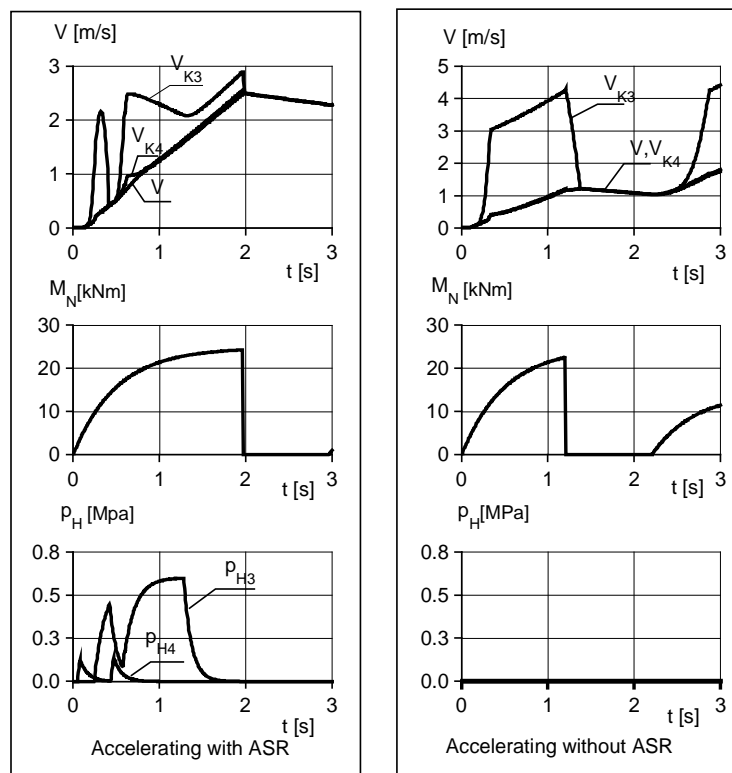
**Fig.1** Physical model of vehicle



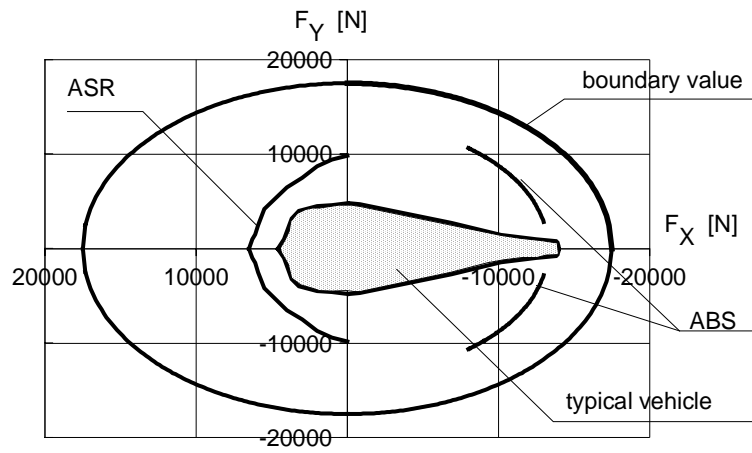
**Fig. 2** Fuzzy set LVV, LWV, LWS and LSB



**Fig. 3** Braking with and without ABS on  $\mu$ -split surface ( $\mu=0.6$  for the left wheels and  $\mu=0.2$  for the right wheels)



**Fig. 4** Accelerating with and without TCS on a homogeneous surface  $\mu=0.2$



**Fig.5** Longitudinal and lateral forces during vehicle braking and accelerating